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Final Report
May 31, 2011

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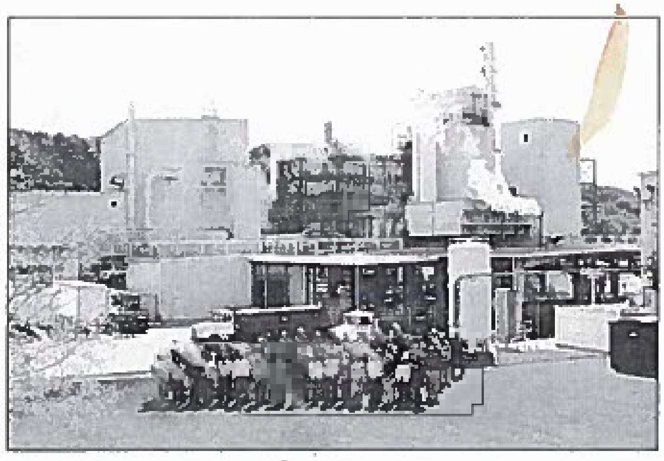
BakerRisk Project No.
01-03359-001-11

INCIDENT INVESTIGATION REPORT

HERITAGE-WTI INCINERATOR INCIDENT

APRIL 12, 2011



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EXECUTIVE SUMMARY

Baker Engineering and Risk Consultants, Inc. (BakerRisk) was requested by Heritage-WTI Inc. (WTI) to assist in the investigation of an explosion that occurred on April 12, 2011 in their incinerator in East Liverpool, Ohio. No one was injured and no damage was reported outside the building.

BakerRisk visited the site immediately after the incident and has reviewed the recovered process data. We have evaluated several possible scenarios and have proposed an explanation as to why damaging pressures propagated through the system.

The incident is consistent with an explosion in the kiln that pushed flammable gases from the secondary combustion chamber (SCC) into the boiler, producing a vapor cloud explosion in the boiler. The boiler explosion created vibrations and/or a pressure wave that caused an ash deposit to fall from near the top of the secondary combustion chamber into the slag tank, splashing out a large volume of water, which flashed to steam. Thus, three events contributed to the incident, probably increasing the event intensity over what would have resulted from each part individually.

The cause of the initial event in the kiln remains unclear. One possibility is that a some energetic material remained in the "PBX ash." Alternatively, there may have been a reaction between feed materials such as alkyl amines or aluminum powder. Alternative causes should be further explored.

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1 INTRODUCTION

Baker Engineering and Risk Consultants, Inc. (BakerRisk) was requested by Heritage- WTI Inc. (WTI) to assist in the investigation of an incident that occurred on April 12, 2011 at their incinerator in East Liverpool, Ohio. WTI incinerates a wide variety of waste materials at the facility. At 10:40 p.m. on April 12, 2011, the system suffered an upset that blew out the shrouds of the kiln and an expansion joint downstream of the boiler. No one was injured in the incident. WTI immediately launched an investigation into the cause of the incident.

The purpose of this work is to document the event and evaluate alternate explanations of what happened.

1.1 Plant Description

Heritage-WTI, Inc. is a RCRA Part B-authorized facility that provides incineration services for hazardous and non-hazardous wastes generated by private industries and public organizations. Started in December 1992, the company accepts, stores, and treats up to 60,000 tons of bulk liquids, bulk solids, containers, and lab packs each year. WTI also provides disposal services for non-hazardous water, fuels, mercury reclamation, industrial maintenance, and electronic waste.

The facility's rotary kiln treats approximately 60,000 tons a year of mixed hazardous and non-hazardous material. Solid residues, slag, and ash, are removed downstream and transported to an authorized hazardous waste landfill for final disposal.

Air emissions are cleaned and scrubbed via a heat-recovery boiler, spray dryer, three-field electrostatic precipitator, and a four-stage wet scrubber. In 2004, Heritage-WTI became the first commercial hazardous waste treatment facility to demonstrate compliance with the US EPA's latest performance standard, the Maximum Achievable Control Technology rule, known as MACT. The facility demonstrated compliance again in 2010. Figure 1 shows an aerial view of the site.

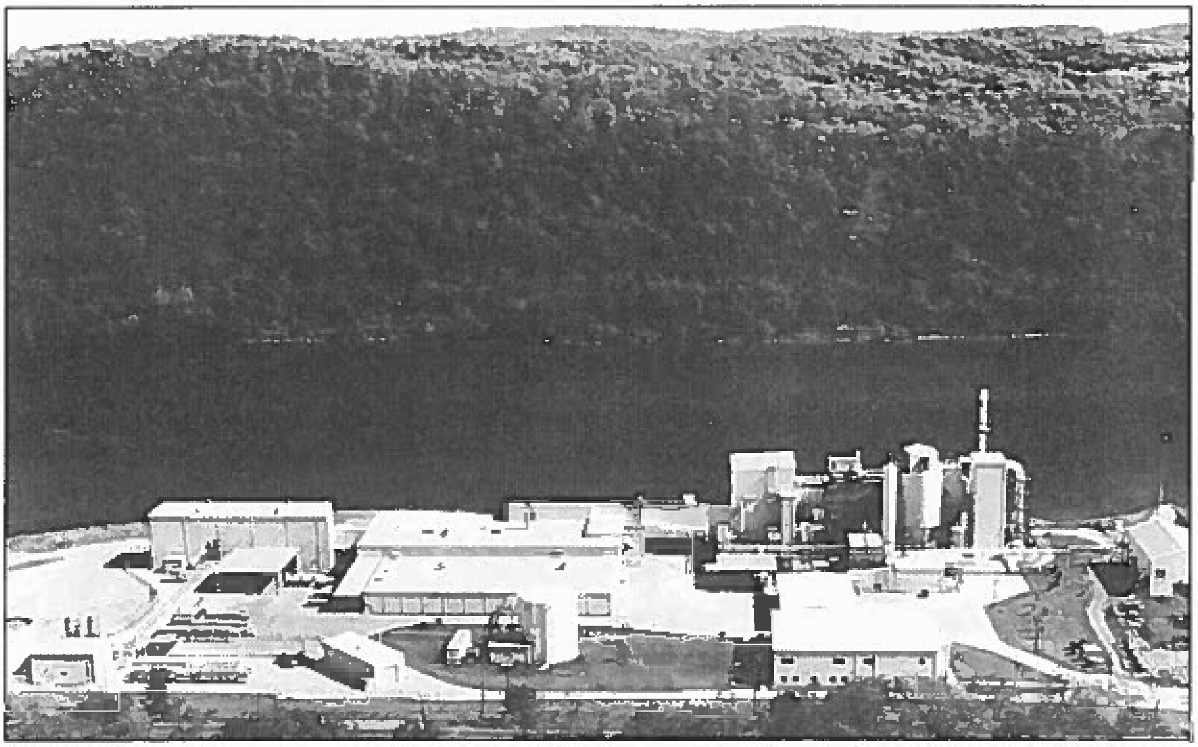


Figure 1. Aerial View of the East Liverpool WTI Waste Site

1.2 Background

The incineration process flow is shown in Figure 2. Loose solids and drums of mixed waste are loaded into the rotary kiln, while liquid wastes are pumped into the kiln through lances. The exhaust from the kiln flows into a secondary combustion chamber (SCC) for additional burning of the process stream. Solids fall from the kiln into a slag tank and the bottom of the SCC. Hot gases from the SCC pass into a boiler to recover excess heat. The gases are further cooled and cleaned as they next flow through a spray dryer, an electrostatic precipitator, and a scrubber before being sent to the stack.

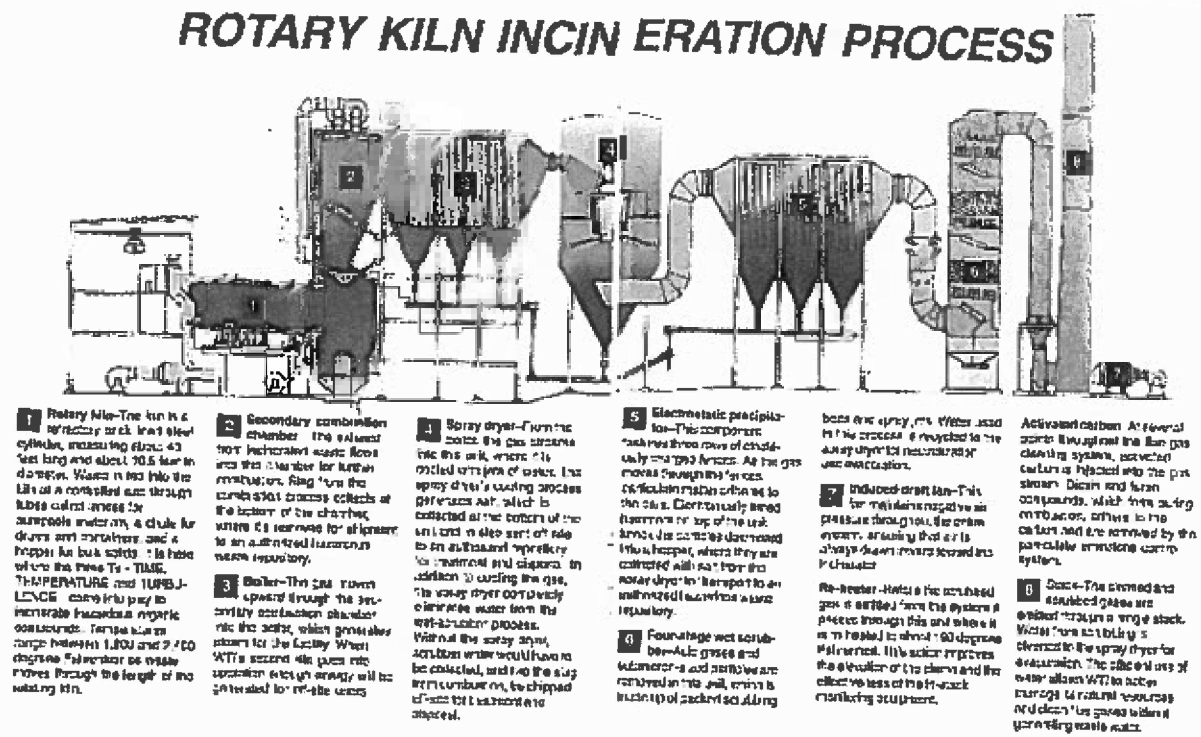


Figure 2. Incineration Process

1.3 Event Timeline[1]

The WTI investigation team was able to recover data covering the process upset from throughout the system. Relevant recorded pressures and their locations are shown in Figure 2. The first indication of the explosion occurred at 22:40:05, which is denoted as t = 1 second. At t = 0, there was no indication of change on any instrument. The data at t = 1 are the first that show pressure spikes, which were indicated on the pressure instruments throughout the incineration train.

A sequence based on pressures (flows, temperatures, etc. were not included) is as follows:

> *22:40:05 (t = 1 s):* This is the first indication in the SCC, just above the top of the kiln inlet, and in the PA fan ductwork.
>
> *22:40:06 (t = 2 s):* Pressure gauges at the PA fan ductwork, SCC (just above kiln inlet), and boiler outlet exceed their instrument ranges. Additionally, pressure is indicated in both kiln shrouds, with the outlet shroud higher and at its maximum. Spray dryer pressure rises.
>
> *22:40:07 (t = 3 s):* Pressure first noticed in the spray dryer outlet, ESP outlet, Scrubber. First change (up) of quench tank level. Kiln inlet shroud hits maximum pressure; outlet shroud already recovering.
>
> *22:40:08 (t = 4 s)*: PA fan ductwork hits its maximum reading; Boiler deltaP (dP) hits both its upper range and maximum reading; Spray Dryer dP hits its max reading; Kiln inlet shroud is recovering, pressure is still high from the SCC to the scrubber. Quench tank level reaches its peak height (before the drop or loss of water level)
>
> *22:40:09 (t = 5 s):* PA fan ductwork begins recovering. SCC, Boiler Outlet, ESP outlet, and Scrubber pressures hit their maximum readings
>
> *22:40:10 (t = 6 s):* First indication of quench tank level drop; SCC to the spray dryer beginning recovery; ESP inlet hits its peak; ESP outlet and scrubber in recovery. PA fan flow begins to increase.

An explanation of the pressure behavior is offered in Section 2. A discussion of alternate explanations with comparisons to the recovered data is provided in Section 3. Some conclusions and recommendations are offered in Section 4.

[1] Christine Shorokey, Status Report, 4/12 Incident Data Analysis, via email, May 13, 2011.

WTI Summary Table – Pressures

4/13/2011 EVENT

Description Bailey Actual	PIC-4471 VRSctnP Upstrm VR Fan	PIC-4407_ VRMixBoxP Dnstrm VR Fan	PI-3419 PA Fan P	PI-4307 Kiln in Shroud In Shroud	Calc'd Out Shroud	Calc'd Lower SCC P	PI-4308A SCC P	PI-4308B SCC P	PDI-4308 Boiler dP In - Out	Calc'd Boiler In	PI-5808 Boiler Dnst	PDI-6000 SpyD air In: B-N	6604_ESPin ESPinP DuctToTop	PI-6605 ESPoutP	PTR-7347 ScrubP 2ndPB dP	PI-7200 ScrubP	[illegible]	LI-4810 Quench TK Level - in
Normal AVG	-1.40	-2.40	-0.17	0.71	6.12	-0.47	-0.41	-0.45	0.11	-0.47	-0.66	1.30	-2.35	-2.70	3.30	-10.65	[illegible]	71.30
22:40:04																	[illegible]	
22:40:05			1.71				0.04	0.17									[illegible]	
22:40:06	-0.03	-0.41	16.19	[illegible]	3.38		3.36	3.24	3.85	5.64	1.89	1.80					[illegible]	
22:40:06	1.56	2.[illegible]							0.33	1.72	1.40						[illegible]	
22:40:07	2.79	9.34		1.81	2.64	3.27	4.96	4.75			3.13		-1.21	-0.40		-8.71	[illegible]	72.72
22:40:08	0.26	11.24	20.86	.50		4.42			5.66			7.33	0.50	13.[illegible]	6.60			76.82
22:40:09	-1.47	5.41	[illegible]		0.06		5.17	4.83	5.40	8.67	3.27	6.44		14.56		-1.50	[illegible]	
22:40:09																1.91		
22:40:10	-2.28	1.18	3.36	1.11		4.33	4.29	3.67	3.33	6.14	1.72	0.85	1.13			-3.11	[illegible]	
22:40:10											1.35				6.09		[illegible]	77.[illegible]
22:40:11	-1.88	-1.59			0.65		2.85	2.46	5.36	2.15	[illegible]		-0.09	0.08	4.13		[illegible]	75.[illegible]
22:40:12			1.76	0.86	0.99	1.88	1.30	1.16	0.71	1.60	0.20	1.25	-1.41	-2.76		-7.90	[illegible]	69.82
22:40:13		-2.93	9.83		0.76		0.72	0.89	0.39	0.46	0.06	2.31	-3.88	-4.55	4.31	-12.78	[illegible]	67.53
22:40:14		-3.06			0.57		0.34	0.33	0.23	[illegible]	-0.02				4.42		[illegible]	66.77
22:40:15												2.80	-3.06	-4.70		-13.43	[illegible]	
22:40:34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Recovery Timestamp	22:40:04	[illegible]	22:40:34	22:41:[illegible]	didn't		didn't	didn't	didn't	didn't	didn't	didn't	22:40:13	22:40:12	didn't	[illegible]	[illegible]	[illegible]
Max	2.79	11.24	20.86	1.89	3.38	4.82	5.17	4.83	5.66	8.67	3.37	7.33	1.13	14.56	6.60	1.51	Max	77.02
Min	-2.28	-3.06	0.83	0.86	0.06	1.88	0.04	0.17	0.23	0.21	-0.02	0.85	-3.86	-4.70	4.13	-14.87	Min	61.79
Delta	4.18	[illegible]	[illegible]	1.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Deviation Duration	[illegible]	[illegible]	[illegible]	[illegible]	n/a	n/a	00:00:34	[illegible]	[illegible]	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.50 in
Recovery Duration	[illegible]	[illegible]	00:03:26	00:01:06	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	00:00:03	00:00:03	n/a	00:02:06	[illegible]	[illegible]
Instrument Range	[illegible]	[illegible]	[illegible]	0 to 10" H2O	n/a	n/a	[illegible]	-3.5 to 2.5"	-5 to 5" H2O	n/a	[illegible]	0 to 8"	-25 to 0"	-20 to 5"		[illegible]	[illegible]	[illegible]

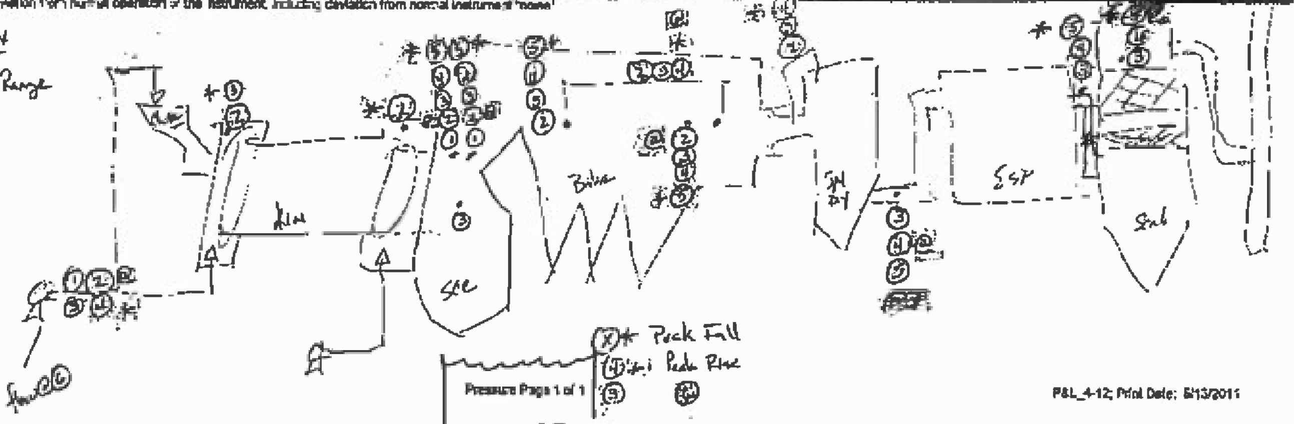
NOTE: Timestamps listed are the first deviation from normal operation of the instrument, including deviation from normal instrument "noise"

* = Actual Max

@ = Instrument Range

①=:05
②=:06
③=:07
④=:08
⑤=:09

⑦=:34
= 29th second into the event



WTI Summary of P-events

P&L_4-12; Print Date: 5/13/2011

Figure 2. Summary Table of Pressures

2 An Explanation of What Happened

1. During time t=1 s, an explosion occurred inside the kiln. The overpressure load from the kiln explosion was sufficient to fail the shrouds, which failed during this first second. The exact source of the explosion is uncertain. There are several possibilities:

    - The PBX ash drums may have also contained some unintended explosive residue.
    - Drums introduced shortly before the explosion may have contained material that reacted with each other.
    - There may have been a drum BLEVE, which suddenly released a large amount of flammable vapor.
    - Flammable vapors may have been drawn into the primary air inlet, which resulted in an explosion in the duct just downstream of the blower.
    - There may have been a metal dust explosion.

    Even though the precise nature of the explosion is not known, the pressure data show that an explosion occurred in the kiln. The remainder of the upsets throughout the system proceeded as a consequence of this initiating event.

    Also during time t=1 s, the kiln explosion pushed burning gases from the SCC into the boiler. The system is designed to normally have unburned fuel in the SCC but not in the boiler. A portion of the unburned fuel in the SCC was driven by an expansion wave from the kiln explosion into the boiler. That pressure wave would have propagated at the speed of sound, about 2200 fps at this elevated temperature. The wave would have traveled from the front of the kiln to the boiler (a distance of about 100 ft) in about 50 milliseconds, and a secondary event in the boiler would have appeared simultaneous to the kiln explosion.

    During the first and second seconds, the flammable vapors that were pushed into the boiler would have produced a vapor cloud explosion (VCE). The flame speed and overpressure created in the VCE were increased by the turbulence-producing congestion of the boiler tubes.[2] Evidence of the boiler VCE is seen by comparing the SCC and boiler pressures at the same moment, as shown in Table 1. This table shows that the recorded pressures in the boiler (at time t = 2 s and beyond) were greater than in the SCC.

[2] The vapor cloud explosion proposed would have been a rapid deflagration and not a detonation. Blast overpressure is produced during a VCE by turbulent combustion occurring at a much faster than usual burning rate, releasing the energy from the combustion process in a much shorter time than usual. The faster burning rate is caused by enhanced turbulence from congestion such as pipes and tubes, and can increase the flame speed from about 0.5 m/s to values of approximately 100 m/s (Mach 0.3).

If this were simply a physical explosion in SCC, the SCC pressures should have been greater than elsewhere in the system. The only way to produce the higher pressures in both the kiln and in the boiler would have been with combustion in those areas. The blast loads created in the boiler VCE were sufficient to fail the expansion joint downstream of the boiler. The boiler received an internal pressure beyond its design capacity, as evidenced by the 7-inch plastic deformation in the walls.

Table 1. Recorded Pressures at Incinerator Locations (Inch WC)

Time	PA Fan PI-3410B	Kiln PT4307	SCC PI 4300A&B	Boiler In PI 5005+PDI4305	ESPin PI 6604	ESPout PI6605
22:40:05	1.71		0.04/0.17			
22:40:06	18.15	0.99	3.38/3.28	5.54		
22:40:07		1.89	4.6/4.75		-1.21	-0.49
22:40:08	20.85	1.5			0.6	10.5
22:40:09	10.32		5.17/4.93	8.67		14.6
22:40:10	3.36	1.12	4.26/3.87	5.04	1.13	
22:40:11			2.85	2.22	-0.09	0.08
22:40:12	1.75	0.86	1.5	1.0	-1.41	-2.76

2. There was a sudden shifting of gas flow at the top of the SCC caused first by the downstream loads from the kiln burst followed by blast loads in the opposite direction from the boiler VCE. At time t = 3 s, this perturbation caused ash to fall from near the top of the SCC into the slag tank, splashing out a large volume of water, which flashed to steam. Two patches of missing ash were noted after the incident—the first on the north wall and the second on the southwest corner of west wall.

   The liquid level in the quench tank rose suddenly and then fell, as shown in Figure 3. The liquid level in the tank dropped more than 20 inches. The splashing of water out of the tank also threw drums and ash from the slag tank. Several inches of ash were on the ground surrounding the tank following the incident.

   The oxygen concentration dropped suddenly in the SCC (as shown in Figure 4), below the 12% needed for combustion. This was caused mainly by the sudden vaporization of water from the slag tank and creation of steam, which displaced the oxygen in the combustion air.

3. The system then vented and cooled.

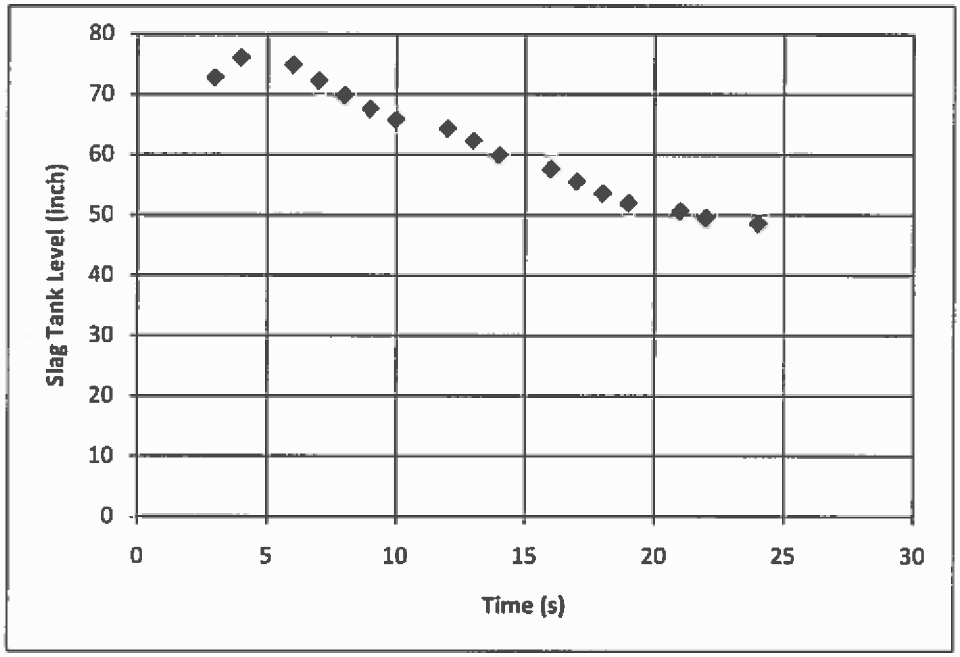


Figure 3. Slag Tank Liquid Level as a Function of Time

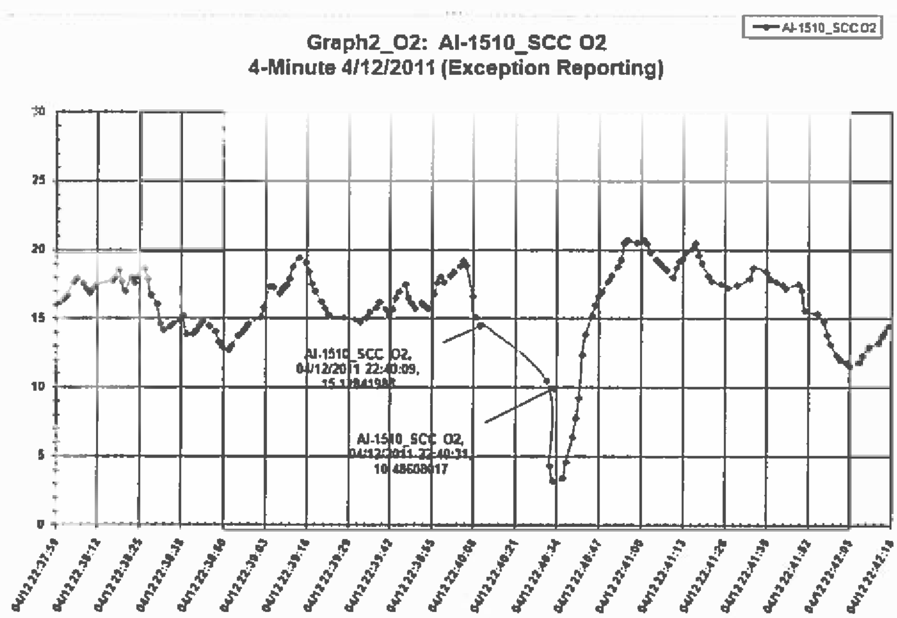


Figure 4. SCC Oxygen Concentration as a Function of Time

3 COMPARISON WITH ALTERNATE SCENARIOS

Several hypothetical scenarios were evaluated to help determine the cause of this incident in light of the complex physical evidence and observations. Several of these scenarios are more likely the result of the explosion, rather than the initiating event.

1. Drum BLEVE/explosion in kiln
2. Massive ash fall from SCC into slag tank
3. Vapor or dust explosion in SCC
4. Unburned hydrocarbon passed through SCC and deflagrated in boiler
5. A portion of the brow falls, allowing molten slag to fall out of kiln into slag tank
6. Slag buildup in SCC loosened by fluoride (scenario 2 with a cause)
7. Change in SCC performance due to lower operating temperature
8. Combined scenario 2 and 4
9. Brow falls and vaporizes

3.1 A Steam Explosion – Rejected

A number of postulated scenarios (Scenarios 2, 5, 6, 8, and 9) suggest that the event was a steam explosion caused by a hot mass falling into the slag tank. There are three inconsistencies with the observations and data.

Timing: The primary reason for rejecting these scenarios is that they are not consistent with the timing of the events. The liquid level of the slag tank does not change until time $t = 3$ s, which is after the pressure rises have been seen, first in the kiln, and then in the boiler.

Relative Pressures: If the event were simply a sudden release of steam from the slag tank, the pressures upstream and downstream of the SCC would not have been higher than in the SCC itself at the same point in time. Table 1 clearly shows pressures in other areas that were greater than in the SCC.

Heat Transfer: BakerRisk did calculations that showed that vaporization from a hot mass suddenly introduced into the slag tank was inconsistent with the dramatic decrease in the level of water in the slag tank following the event. The volume of water vaporized from the heat of the dumped object would be roughly equaled by the displacement caused by the object itself. Adding hot items should not have lowered the tank water level significantly.

BakerRisk suggests that the water was removed by splashing. Equating the momentum of ash falling from the SCC to the momentum needed to splash the water from the tank produces the curve shown in Figure 5. This chart shows the approximate dimension of a square piece of ash dropped from the top of the SCC (46 ft, assuming an ash specific gravity of 2) that would produce the observed water displacement. This is a reasonable explanation of the loss of water from the slag tank.

BakerRisk does not believe that a pressure wave alone could have caused the water displacement from the slag tank. Such a pressure wave would cause sloshing of the water only to the extent that it was uneven—a uniform pressure applied to the surface of the water would not displace any water. The degree of non-uniformity of the pressure wave is unknown, but the location of the slag tank would minimize its effect. Also, the magnitude required of a pressure wave required to displace 2 feet of water from the tank would probably have produced more damage to the SCC.

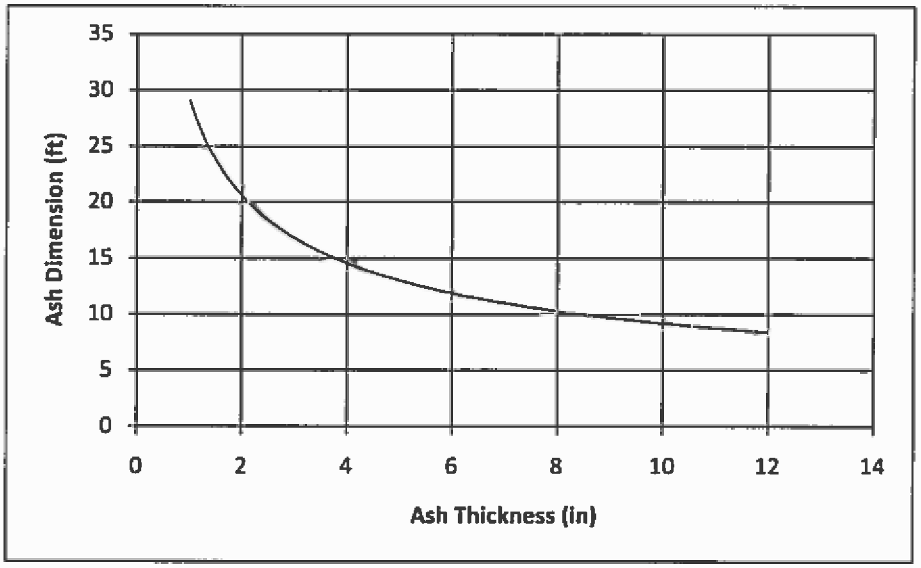


Figure 5. SCC Ash Size Consistent with Water Level Change

3.2 A Vapor or Dust Explosion in the SCC - Rejected

An explosion originating in the SCC should not have caused elevated pressures in the kiln before the pressure increased in the SCC. Again, the data point to an explosion initiating in the kiln.

3.3 The Remaining Scenarios – Components in a Complex Explosion

The evidence suggests that there was an ash fall from the SCC into the slag tank (Scenario 2), but that the fall was a consequence of the initial explosion(s) rather than the cause. Likewise, we believe that flammable material made its way into the boiler and deflagrated (Scenario 4), but such a boiler explosion does not explain the early pressure spike in the kiln. The boiler VCE was the consequence of flammable gases being driven into the boiler by the first overpressure in the kiln.

This leaves two remaining scenarios that may explain the event. A BLEVE or another sort of explosion in the kiln seems consistent with being the initiating event, causing the secondary boiler VCE and slag tank event. It is a concern that there is no real measure of how much of the combustion occurs in the SCC. It is possible that lowering the operating temperatures has increased the region of flammable gases inside the SCC. Understanding where the combustion in the SCC is taking place would aid in controlling/preventing combustion from reaching the boiler.

4 Conclusions and Recommendations

As a result of our analysis, BakerRisk has reached the following conclusions:

- The April 12th incident is consistent with an explosion in the kiln that pushed flammable gases into the boiler, producing a secondary vapor cloud explosion.
- Most of the SCC volume must have been filled with a flammable mixture such that the kiln explosion could push a flammable mixture to the boiler. Monitoring the gases in the upper portion of the SCC may help to determine whether the process conditions are allowing a flammable mixture to approach the boiler. Adding an oxygen sensor and/or a fire eye near the top of the SCC might provide an indication of whether combustion extends into the upper portion of the SCC.
- The current safe operating limits might be reviewed to confirm that they are consistent with the original design basis of the kiln and SCC.
- WTI may consider reviewing its screening procedures to see if additional safeguards might be put in place to prevent too many drums of material that might interact from being in the kiln at the same time.
- WTI may consider adding a temperature sensor in the slag tank.